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TECHNICAL REPORT ARLCB-TR-83012

GUN TUBE EXTRUSION

R. A. FARRARA

APRIL 1983



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET N.Y. 12189

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Hollow, two diameter, thick walled cylinders were produced via the hot extrusion process by the Curtiss-Wright Corp., Buffalo, New York. The material was gun steel (4335V modified) produced by Electralloy Corp., Oil City, PA, in an argon-oxygen decarburization (AOD) vessel. The extrusions were heat treated to develop mechanical properties required for the 105mm M68 gun tube per the Specification MIL-S-46119. Mechanical properties (tension, charpy V-notch and fracture toughness specimens) were measured		

20. ABSTRACT (cont'd)

in the transverse and longitudinal directions along the length of three (3) extrusions. The macrostructure and microstructure were also examined. The mechanical properties were satisfactory; however, the charpy V-notch impact energy was marginal. The dimensions, straightness, and wall thickness variations were consistent and met the requirements. Although more material had to be removed, compared to conventional forgings, the total time for machining an extrusion would not be more than for conventional forgings because they are easier to straighten and set up than the normal tapered forgings.

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STATEMENT OF THE PROBLEM

Conventional gun tube forgings are produced as open die forgings. An alternative source for hollow cylinders of gun steel is potentially available using the extrusion equipment/heat treating capability of the Curtiss-Wright - Buffalo Facility. The problems were to determine if (a) the heat-treated extrusions possess the required mechanical properties for gun tube forgings per MIL-S-46119 and (b) the configuration of the extrusions allows this process to be economically competitive, from a machining viewpoint, with the conventional forging configuration.

BACKGROUND

a. Extrusion Process. The extrusion equipment at the Curtiss Wright Facility produces a thick-walled, two outside diameter, hollow cylinder. A hollow ingot (hole is produced by a trepanning operation) is heated to approximately 2200°F via induction equipment. The heated ingot is extruded using a horizontal 12,000 ton extrusion press. The horizontal ram forces the steel longitudinally and radially through taper dies onto a mandrel. Two sets of dies were employed for generating the two external diameters. The final extruded product is shown in Figures 1 and 1A. The reduction in area for the breech (large diameter) and muzzle (small diameter) was 5.5/1 and 9.3/1 respectively.

b. Material - Melting Process. The steel ingot was the typical gun steel composition (Figure 1A) and was produced by the Electralloy Corporation, Oil City, PA, in an argon-oxygen decarburization vessel. This process involves continuous

injection of argon and oxygen into the molten steel (originally melted in an electric arc furnace) causing violent stirring action and intimate mixing of slag and metal which lowers the sulphur content to low levels (.01% max.).

c. Processing after Extruding. After extruding, the tube was normalized and tempered, and straightened if necessary. It was then cropped to length, grit blasted, and cleaned of scale and lubrication in preparation for hardening and tempering.

d. Heat treating. The heat treating equipment consists of a gas fired furnace (40' long and 8' wide) and a horizontal water immersion quench tank (42' long x 11' wide x 5' deep) equipped with agitators and a cooling tower. The gun tube forging specification requires the tube to be in a vertical position during quenching, however, deviation from this requirement was allowed for the extrusions. After heating the tube to 1550°F in the austenitizing furnace, it was immersed horizontally into the violently agitated water while simultaneously pumping water through the bore. Tempering occurred within thirty minutes after quenching, in a different furnace than the one used for austenitization, at 1060°F for four hours.

e. Requirements. The extrusion was produced to the dimensional requirements of Figure 1A. The mechanical property requirements are as follows:

<u>Yield Strength (.1% offset) psi</u>	<u>Minimum Reduction of Area (%)</u>		<u>Minimum Charpy V-notch Impact Strength at -40° ± 2°F</u>	
	<u>Transverse</u>	<u>Longitudinal</u>	<u>Transverse</u>	<u>Longitudinal</u>
160,001-170,000	25	35	15	25
170,001-180,000	25	35	15	20

The macrostructure requirement is that it shall be equal to or better than S-2, R-2, and C-3 of ASTM E381.

APPROACH TO THE PROBLEM

a. Mechanical Properties:

(1) Tensile and Charpy V-notch specimens - Transverse and longitudinal tensile and charpy V-notch specimens from both ends and from the middle of the large and small diameter straight zones were tested to obtain yield strength, reduction-in-area and charpy impact energy data.

(2) Fracture toughness and crack propagation rate values - Transverse fracture toughness specimens from both ends and from the large and small diameter straight zones were tested to obtain fracture toughness and crack propagation rate data. These properties are not required in the gun tube specification (MIL-S-46119), but are important for a complete evaluation. The questions were: Does this material possess the fracture toughness expected of gun tube forgings; does it show the normal correlation between fracture toughness and charpy impact strength; and, does a crack propagate at the rate that is typical of material supplied by other producers?

b. Cleanliness/Structure:

Macro and micro structure were examined to determine cleanliness and were compared to tube forging material produced via the conventional and rotary forge processes.

c. Economics:

Three (3) extrusions were machined to the prior-to-swage autofrettage configuration. The advantages/disadvantages were evaluated and compared to tube forgings produced via the conventional and rotary forge processes.

RESULTS

a. Mechanical Properties.

(1) Tensile and Charpy V-notch values:

(a) Tested by Curtiss-Wright Corp. (Table I) - All tubes had acceptable values, i.e. they were within the requirements, except the muzzle end of tube #7 had one charpy V-notch value of 14 ft-lbs (15 ft-lb minimum is required). The yield strength values at the breech end were higher than at the muzzle end and the charpy V-notch values were, in general, marginal.

(b) As-received extrusions tested at Watervliet Arsenal (Table II) - The transverse yield strength values were higher and the charpy V-notch values were lower than reported by Curtiss-Wright. The longitudinal yield strength was approximately the same as the transverse yield strength. However, the longitudinal reduction-in-area and charpy V-notch impact strength values were significantly higher than the similar transverse measurements.

(c) Retempered 25°F higher than original temperature (Table III) - Since the yield strength of the as-received extrusions was high (approximately 175 ksi) and the charpy impact strength was low (less than 15 ft-lbs), it was decided to retemper a muzzle end from one extrusion. The retempering temperature was 1085°F which is 25°F higher than the original tempering temperature. The yield strength was reduced by approximately 7 ksi and the charpy impact energy was raised by approximately 4 ft-lbs.

(d) Reheat-treat breech ends - Since the charpy impact energy was marginal even after retempering at 1085°F, two (2) cylinders (9.34 Ø OD x 3.68 Ø ID x 12 inch long) from the breech end of one extrusion (#10) were

reheat-treated. The heat treating procedure and the transverse tensile/charpy impact energy data are reported in Table IV. The yield strength was lowered from approximately 170 ksi to 164 ksi and the charpy impact energy was raised from approximately 16-ft-lbs to 20 ft-lbs.

(e) Reheat-treat complete extrusions - Since the results from reheat-treating breech ends were encouraging, three (3) extrusions were reheat-treated in the horizontal equipment at Watervliet Arsenal. The heat-treating procedure and the transverse tensile/charpy impact strength data are reported in Table V. Two (2) extrusions (#1 & #4) were tempered at 1100°F and one (1) extrusion (#8) was tempered at 1080°F. Extrusion #1 had adequate charpy impact strength and the yield strength at the breech end was satisfactory, however, the yield strength at the muzzle end was slightly below the required minimum (160 ksi). Extrusion #4 had adequate yield strength and charpy impact energy at both ends. Extrusion #8 had higher yield strength and lower charpy impact energy than either #1 or #4. The charpy values were marginal (15.5 ft-lbs at the muzzle and 14.5 ft-lbs at the breech).

(2) Fracture toughness and crack propagation:

(a) As-received extrusions; Fracture toughness - Transverse "C" shaped fracture toughness specimens were tested from both ends and from the middle of the large and small diameter zone of the three (3) as-received extrusions tested for tensile and charpy values. The fracture toughness at room temperature data is listed in Table VI. The fracture toughness in the breech of the three (3) extrusions was above 100 ksi $\sqrt{\text{in}}$ (range of 106.4 to 116.4) but in the muzzle, it was below 100 ksi $\sqrt{\text{in}}$ except for one specimen (range of 92.4 to 102.3).

(b) As-received extrusions; Crack propagation rate -

Transverse "C" shaped specimens were tested from both ends of two (2) as-received extrusions that were tested for tensile and charpy values. The crack propagation rate at room temperature data is listed in Table VII. The propagation rates were slightly lower than the typical rates measured on gun tube material. The optical technique was used to measure the crack growth.

b. Cleanliness/Structure:

Macrostructure - The structure was uniform and well within the R2, S2, C3 requirements of ASTM E381.

Microstructure - The microstructure of a charpy specimen from the breech end of extrusion #11, in the as-received condition, revealed martensite throughout. However, aluminum oxide inclusions were prevalent and a few manganese sulfide inclusions exist (Figure 2).

c. Machining - The required and actual dimensions/straightness of the six (6) extrusions are listed in Table III. All of the extrusions met the requirements. Only one (1) extrusion was machined to the prior-to-swage configuration. The plan was to machine the three (3) extrusions that were reheat-treated in the horizontal equipment at Watervliet Arsenal. Unfortunately, all three (3) extrusions developed longitudinal cracks in the bore, hence the one (1) extrusion that had the fewest cracks was selected for machining. This extrusion was machined without any problems and was easier to straighten and set up for machining than the present rotary forged tubes. Comparing the route sheets for the extrusion to the rotary forge tube reveals a unit decrease of 3.5 hours.

DISCUSSION OF RESULTS

a. Mechanical Properties.

(1) Tensile and Charpy V-notch Values - The tensile and charpy values measured at Curtiss-Wright and at Watervliet Arsenal on the as-received extrusions indicated that the yield strength was significantly above the minimum required; however, the charpy impact energy was marginal. This problem is directly related to tempering at too low a temperature. Retempering material at 1085°F (original temperature applied by Curtiss-Wright was 1060°F) improved the balance between strength and toughness. Complete reheat treatment of both short cylinders and full length extrusions confirmed that the original material was properly quenched (100% martenistic structure); however, the tempering temperature was too low. The data from retempered and reheat-treated material indicates that the material furnished by Electralloy/Curtiss-Wright could satisfy the requirements.

(2) Fracture Toughness - The fracture toughness (92.4 - 112.1 ksi $\sqrt{\text{in.}}$), Table VI, correlates with the nominal relationship between fracture toughness and charpy impact energy (12.0 - 15.5 ft-lbs), Table II. The fracture toughness of conventional gun steel is typically higher (110 - 125 ksi $\sqrt{\text{in.}}$) than what was measured in the extrusions.

(3) Crack Propagation Rate - The crack propagation rate data, Table VII, indicates that a given crack growth rate (da/dn) occurs in the extrusion material at about a 10% higher load (ΔK) than that in conventional gun steel. This indicates that the extrusion material is marginally better in fatigue than normal, but a 10% difference is within the expected spread from scatter.

b. Cleanliness/Structure - The macrostructure and amount of sulfides is typical of gun steel provided by other suppliers; however, the aluminum oxide content was higher than typical. Aluminum is added to the argon-oxygen vessel and is oxidized for the purpose of supplying heat to the melt (there is no external heat applied to an AOD vessel). Bath temperature has to be controlled in order to control the removal of carbon, which is initially high due to the inexpensive high-carbon ferrochromium used in the electric arc furnace charge, and prevent the removal of chromium. The microstructure, which was judged to be 100% martensite, is typical of properly or fully quenched gun steel.

c. Machining - The extrusion process provides excellent dimensional/wall variation/straightness control. Since there is a considerable amount of extra material on the OD of the extrusion compared to the conventional (rough machined) and rotary forged tubes, it was anticipated that there would be an increase in manufacturing time. However, the extrusion process results in small wall variations (OD is relatively concentric to the ID) and results in a relatively straight, non-twisted, residual stress-free hollow cylinder which is simple to straighten and set-up for machining. The actual machining time is less than the rotary forged tubes and approximately the same as conventional, rough turned tubes.

CONCLUSIONS

a. Curtiss-Wright can extrude and heat treat gun steel supplied by Electralloy Corp. that conforms to the gun tube forging mechanical property requirements.

b. The material contains aluminum oxide inclusions which are not prevalent in gun steel from the present suppliers. These inclusions contribute to anisotropy; however, the magnitude of the difference between longitudinal and transverse charpy impact strength is typical of material supplied from the present suppliers.

c. Extrusions would be competitive with the present forgings (conventional and rotary forged) relative to machining cost.

TABLE I

Transverse midwall specimens from both ends - Tested by Curtiss Wright Corp.
 Four (4) Tension and Four (4) Charpy V-notch Specimens from each end

<u>TUBE #</u>	<u>LOCATION</u>	<u>RANGE IN YIELD STRENGTH(ksi)</u>	<u>RANGE IN REDUCTION IN AREA(%)</u>	<u>RANGE IN CHARPY IMPACT STRENGTH @ -40°F (ft-lbs)</u>
1	Breech	165.4-168.1	29-36	15-16
	Muzzle	162.1-163.4	34-39	17-18
4	Breech	168.7-170.8	35-43	17-20
	Muzzle	169.8-171.0	41-48	19-20
7	Breech	166.6-168.5	26-36	15.5-16
	Muzzle	161.5-165.1	26-30	* 14-15
8	Breech	167.1-170.1	26-34	16-17
	Muzzle	162.3-164.1	26-37	15.5-16
10	Breech	169.8-172.9	29-33	15-15.5
	Muzzle	160.0-165.8	33-38	18-19.5
11	Breech	169.8-171.3	28-38	15.5-16.5
	Muzzle	160.9-164.7	28-32	15-16
Required per MIL-S-46119		160-180	25 Min.	15 Min.

* 14 ft-lbs is below requirement of 15 ft-lbs minimum, hence, tube #7 would be rejected. All other tubes have acceptable properties, but Cv values are marginal.

TABLE II

Transverse and Longitudinal Specimens (midwall)
 of As-Received Extrusions - Two (2) Tension and two (2) Charpy V-notch
 specimens from each location

<u>Location</u>	Transverse			Longitudinal		
	<u>Y.S. (ksi)</u>	<u>%RA</u>	<u>Cv @ -40°F (ft-lbs)</u>	<u>Y.S. (ksi)</u>	<u>%RA</u>	<u>CV @ -40°F (ft-lbs)</u>
<u>TUBE #7</u>						
Breech	170.8/170.8	38.5/42.0	14.5/14.5	170.8/169.3	51.0/49.4	25.0/27.0
Muzzle	172.3/175.9	38.5/38.5	13.5/13.5	172.3/173.8	56.3/55.3	14.5/25.5
Center Breech	169.3/170.8	26.6/34.0	14.0/15.5	166.3/167.8	54.4/49.8	22.0/25.5
Center Muzzle	164.8/169.3	54.8/26.1	14.5/15.0	169.3/164.8	35.8/55.8	28.5/28.5
<u>TUBE #10</u>						
Breech	171.8/172.7	26.6/38.5	14.0/14.5	172.7/172.7	56.3/56.3	25.5/26.5
Muzzle	175.7/175.7	33.6/39.4	12.5/12.5	172.7/172.7	57.3/58.3	15.5/15.5
Center Breech	175.8/177.2	36.8/39.4	13.5/14.0	174.2/172.7	52.9/51.4	23.5/24.5
Center Muzzle	168.2/175.7	33.6/40.3	13.0/13.5	166.6/162.1	57.3/57.5	27.0/27.0
<u>TUBE #11</u>						
Breech	172.7/172.7	35.4/38.5	14.0/15.0	166.6/178.8	56.8/54.8	28.5/25.5
Muzzle	172.7/172.7	37.7/42.0	12.0/14.0	174.2/174.2	53.6/55.8	25.3/25.0
Center Breech	175.7/175.7	28.5/35.4	12.5/14.5	174.2/174.2	54.8/54.8	23.5/21.0
Center Muzzle	166.6/169.7	37.7/39.4	14.0/14.3	178.8/177.2	59.2/60.4	27.5/30.0
Required per MIL-S-46119	160/180	25 min.	15 min.	160/180		

TABLE III

Material from Extrusion #7, Muzzle End, Retempered at 1085°F
Original temper was 1060°F
As-Received vs. Retemper - Transverse Specimens

<u>As Received</u>	<u>Retempered at 1085°F</u>
Yield Strength (ksi)	172.3/175.9
Reduction in Area (%)	38.5/38.5
Charpy V-Notch (ft-lbs)	13.5/13.5
Impact Strength @ -40°F	16/18

TABLE IV

Reheat treated Breech Ends from Tube #10
 Transverse Tensile and Charpy Specimens

Reheat Treatment - Normalize at 1850°F/3 hrs; austenitize at 1550°F/3 hrs; water quench, temper at 1085°F/3 hrs; re-austenitize at 1550°F/3 hrs; water quench; temper at 1085°F/3 hrs.
 (Time is furnace time)

	<u>YS (ksi)</u>	<u>RA (%)</u>	<u>Cv @ -40°F (ft-lbs)</u>
As Received	169.8/171.3	28/38	15.5/16.5
Piece a	162.7/163.3	28/31.8	20.5/20.7
Piece b	163.3/166.9	36.8/39.8	19/20

TABLE V

Reheat treated Extrusions in Horizontal Equipment
 Bldg. 135 at Watervliet Arsenal

Heat Treatment - Austenitize at 1560-1580°F/3 hrs; water spray quench OD & ID; Tube #1 & #4 temper at 1100°F/5 hrs; Tube #8 temper at 1080°F/5 hrs.

(Time is furnace time)

<u>Tube #</u>	<u>Location</u>	<u>Yield Strength (ksi)</u>	<u>RA (%)</u>	<u>Cv @ -40°F (ft-lbs)</u>
1	Breech Muzzle	162.6/162.6 158.1/159.6	42.8/43.6 40.7/36.3	18.3/20.0 17.5/17.5
4	Breech Muzzle	165.6/165.6 164.1/165.6	43.6/46.2 44.9/48.6	21/22 23/23
8	Breech Muzzle	172.7/172.7 169.7/169.7	38.5/35.4 37.7/34	14.5/14.5 15.5/15.5

NOTE: All three (3) extrusions developed longitudinal cracks.

TABLE VI

Transverse ("C" shaped) Fracture Toughness Specimens
of As-Received Extrusions

Tube #	Location	Transverse K_{Ic} (ksi $\sqrt{\text{in}}$)
7	Breech	107.4/107.5
	Muzzle	94.1/96.7
	Center Breech	109.1/113.2
	Center Muzzle	94.6/96.2
10	Breech	106.4/110.3
	Muzzle	97.0/98.7
	Center Breech	115.3/116.4
	Center Muzzle	92.4/97.2
11	Breech	111.9/112.1
	Muzzle	95.5/102.3
	Center Breech	111.7/114
	Center Muzzle	95.6/97.7

TABLE VII
 Transverse "C" Shaped Specimen
 Crack Propagation Rate of As-Received Extrusions

<u>Tube #</u>	<u>Location</u>	<u>Applied ΔK</u> (ksi $\sqrt{\text{in}}$)	<u>da/dn</u> in/cycle	<u>Typical ΔK to</u> <u>produce da/dn</u> (ksi $\sqrt{\text{in}}$)
7	Breech	27.3	5.6×10^{-6}	25.4
	Center Breech	27.3	4.7×10^{-6}	24
	Muzzle	35.1	12.0×10^{-6}	32.5
11	Breech	27.3	4.5×10^{-6}	23.6
	Center Breech	27.3	6.8×10^{-6}	27
	Muzzle	35.1	9.5×10^{-6}	30.2

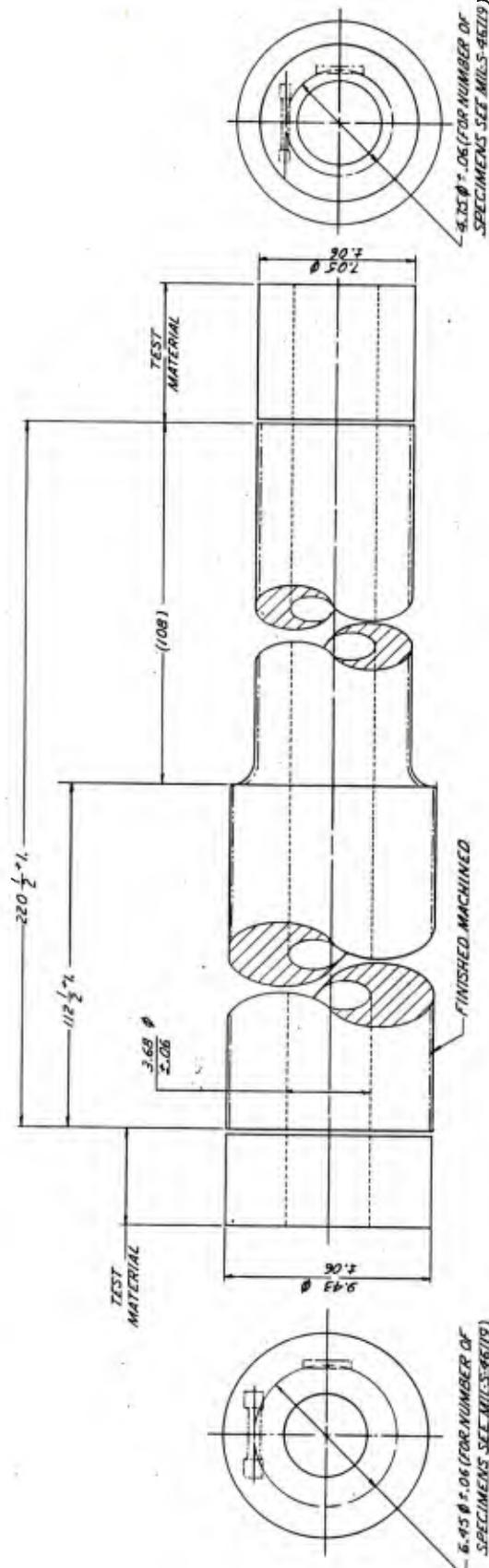
TABLE VIII

DIMENSIONS - 105mm M68 TUBE EXTRUSIONS (Curtiss Wright)

	Dwg. Req't	#1	#4	#7	#8	#10	#11	Extrusion Number	
Length	220-1/2 + 1.0	221-1/4	222-1/8	221-5/16	221-1/4	221-3/16	221-1/4		
(Breech ID (Muzzle)	9.34 ± .06	9.395/9.400	9.400/9.400	9.382/9.398	9.455/9.454	9.391/9.397	9.389/9.384		
	7.05 ± .06	7.046/7.019	7.019/7.023	7.012/7.019	7.016/7.025	6.912/6.905	7.007/6.997		
(Breech ID (Muzzle)	3.68 ± .06	3.730/3.729	3.724/3.736	3.736/3.735	3.726/3.736	3.760/3.750	3.740/3.738		
		3.708/3.707	3.725/3.726	3.715/3.733	3.680/3.689	3.688/3.683	3.688/3.679		
Wall Variation (Max Value)	.08 Max	.07 Breech .018 Muzzle	.057 Breech .068 Muzzle	.012 Breech .065 Muzzle	.062 Breech .012 Muzzle	.027 Breech .008 Muzzle	.018 Breech .061 Muzzle		
Straightness	.375 TIR Max	Met	Met	Met	Met	Met	Met		
	.120 TIR/54"	Met	Met	Met	Met	Met	Met		



Figure 1. ACTUAL EXTRUSION



NOTES:

1. OVERALL EXTRUDED ROUNOUT: A REFERENCE AXIS SHALL BE ESTABLISHED FROM THE O.D. AT EACH END OF THE FORGING, WHEN SUPPORTED ON THE O.D. AT EACH END AND ROTATED 360° THE MAXIMUM ROUNOUT OF THE EDGINGS O.D. SHALL NOT EXCEED 3/16 IN. THE ROUNOUT SHALL NOT VARY MORE THAN 1/20 IN. IN ANY 54 INCH INTERVAL ALONG THE FORGING LENGTH.

2. WALL THICKNESS: VARIATION IN WALL THICKNESS AT ANY TRANSVERSE SECTION SHALL NOT EXCEED .0010 INCH.

3. MECHANICAL PROPERTIES (TRANSVERSE SPECIMENS)

A.) YIELD STRENGTH (1/2" GAGE LENGTH)-160/180 KSI
B.) REDUCTION OF AREA - 25% MIN

C.) CHARPY V-NOTCH IMPACT STRENGTH - 40-2277/1575 LBS MIN

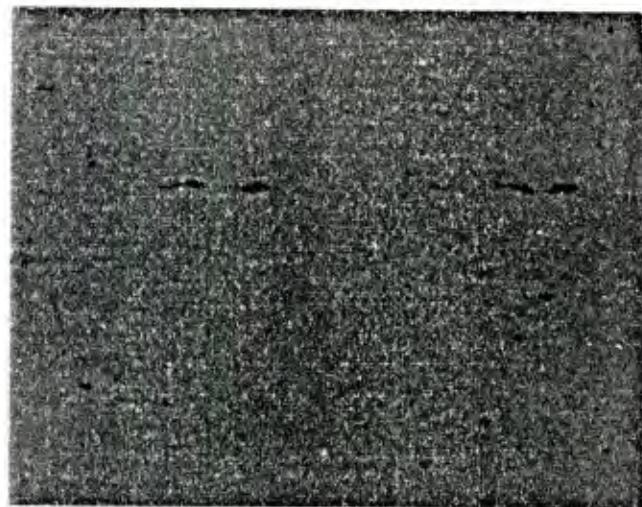
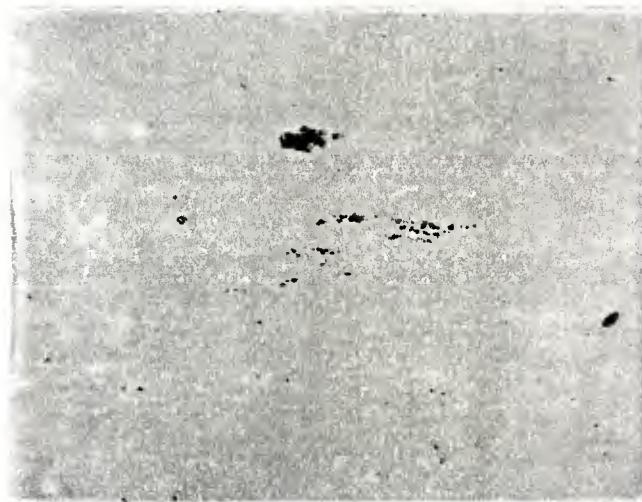
4. CHEMISTRY
RANGE

C	Mo	P	S	Si	Cr	Ni	V
.31/.38	.55/.75	.01 MAX	.25 MAX	.37/.3	.27/.27	.31/.65	.04/.12

5. MACRO STRUCTURE: R2, S2, C3 OR BETTER PER ASTM-E391.

6. WEIGHT AS EXTRUDED (TEST MATT NOT INCL) 2716 LBS
WEIGHT-ROUGH MACHINED 2836 LBS

Figure 1A. EXTRUSION - GUN TUBE



MICROSTRUCTURE - ALUMINUM OXIDES
Fig. 2

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